AD-A256 260

NAVSWC TR 91-446

(2)

A COMPARISON OF ULTRASONIC AND MECHANICAL TEST VALUES OF THE PRINCIPAL YOUNG'S MODULUS OF UNIDIRECTIONAL METAL MATRIX COMPOSITES

BY JOHN V. FOLTZ AND ALBERT L. BERTRAM

RESEARCH AND TECHNOLOGY DEPARTMENT

5 AUGUST 1991

Approved for public release; distribution is unlimited.

NAVAL SURFACE WARFARE CENTER

Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

A COMPARISON OF ULTRASONIC AND MECHANICAL TEST VALUES OF THE PRINCIPAL YOUNG'S MODULUS OF UNIDIRECTIONAL METAL MATRIX COMPOSITES

BY JOHN V. FOLTZ AND ALBERT L. BERTRAM
RESEARCH AND TECHNOLOGY DEPARTMENT

5 AUGUST 1991

NAVAL SURFACE WARFARE CENTER
Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

FOREWORD

Guided ultrasonic waves can be used to characterize materials. However, there sometimes exists skepticism among engineers as to whether the elastic constants determined by the ultrasonic method agree with the values measured by quasi-static mechanical testing. The work herein is a data summary comparing results of the two test methods for Young's modulus in the fiber direction of several unidirectional metal matrix composite materials.

Funding was provided by the Spacecraft and Strategic Missile Materials Block program.

Approved by:

C. E. Mueller

C.E. MUELLER, Head
Materials Division

Accession For		
NTIS GRA&I	☑	
DTIC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

ABSTRACT

A method of determining the fiber direction elastic modulus of a thin-ply unidirectional fiber reinforced metal matrix composite using ultrasonic plate waves is described. The results obtained by the ultrasonic technique are compared to values of Young's modulus from mechanical tests on the same materials. The agreement shows that the ultrasonic method is a reliable and essentially nondestructive way of determining Young's moduli in thin unidirectionally reinforced metal matrix composites.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

Metal Matrix Composites (MMCs) are under development for a number of applications. A principal member of the composite family is the lamina with long fibers aligned parallel to one another -- the so-called unidirectional or uniaxial ply. A lamina with this type of fiber layup serves as the basic building block from which the designer develops a more complicated structural laminate. In the case of MMCs, the unidirectional configuration can also be employed as a structural element without cross-plying. Due to the general relevance of the unidirectional ply, a means of nondestructively characterizing its performance features in the fiber direction is of value. Previously, a method was described for determining the elastic constants of MMCs by ultrasonic plate waves.[1] The present work utilizes a similar procedure to obtain Young's modulus in the fiber direction for a number of unidirectional MMCs. The results are compared to the values of Young's modulus obtained from mechanical tension or compression tests on the same materials.

APPROACH

An extensional plate wave which propagates in the fundamental symmetric Lamb mode is introduced into a thin piece of composite material via an ultrasonic transducer in contact with one edge of the material. The transducer used in this work produces a broadband spectrum centered on a frequency of 1/2 MHz, generating waves which roughly satisfy the condition $L/h >> 1$, where

L = wavelength of the ultrasonic wave,
h = thickness of the material,

When $L/h >> 1$ configurational dispersion caused by the plate free surfaces has a minor effect on the ultrasonic wave speed.[2] Consequently, the Young's modulus of the material can be calculated from Equation (1)

$$E_{11} = p(V_{11})^2 R \qquad (1)$$

where

E = Young's modulus,
v = wave velocity,
p = density,
11 = subscript to indicate fiber direction,
R = parameter dependent upon Poisson's ratio.

The parameter R is typically in the range of 0.94 to 0.99 for most unidirectional MMCs. R is discussed in the Appendix.

The form of the MMC specimens was either flat plate, strips of panels, or simple structural elements such as tubes, C-sections, or L-sections. In all cases the specimens were much thinner than the wavelength of the ultrasonic wave and were oriented so that the wave propagated in the fiber direction. The speed of the wave was measured using a through-transmission approach with a delay block of either PMMA or Al. A fiducial mark was obtained on an oscilloscope screen by sending an ultrasonic pulse through the delay block and into a receiving transducer that was identical to the transmitting transducer. A similar procedure was followed with the specimen in place on the delay block and the temporal displacement of the oscilloscope signal, which corresponded to the transit time of the pulse through the specimen, was read directly from the face of the screen. The plate wave velocity was calculated from the specimen length and the transit time. This information, together with a value for density obtained from specimen weight and geometry and an estimated value of R, permitted E_{11} to be calculated via Equation (1).

TEST RESULTS

Fifteen specimens of graphite fiber reinforced aluminum (Gr/Al) were fabricated at the Naval Surface Warfare Center using precursor material obtained from the Celanese Corporation, Summit, New Jersey. The precursor material was a flexible tow of 12,000 graphite filaments which were coated with Al by an ion-plating process. The fiber, sans Al, has the trade name Besfight HT-7-12000, a diameter of 0.28 mil and a Young's modulus of 30 MSI. The Al-coated tow was consolidated in a hot-press into rectangular strips of panel 107 to 115 mm long (the length is the fiber direction), approximately 18 mm wide and 1 mm thick. The strips had a nominal fiber fraction of 40 percent by volume. As part of the fabrication study, consolidation time in the press was deliberately varied over the specimen set with the result that some specimens were not fully densified. The plate wave velocity was determined in the fiber direction for each sample and is given in Table 1; in general, it is seen to be slightly more than 7 mm/μsec. Using this value and the equation

$$V = fL \qquad (2)$$

where $f = 1/2$ MHz, the wavelength L is calculated to be 14 mm. The ratio of wavelength to panel thickness in these strips is therefore on the order of 14 to 1, i.e., $L/h = 18$. The ultrasonic Young's modulus was calculated using Equation (1) with an estimated value of $R = 0.98$. Each strip was then subjected to a tension test in an Instron Universal Testing Machine to determine the mechanical value of Young's modulus.[3] All data pertaining to this set of specimens are presented in Table 1.

Three 1/2-inch wide by 6-inch long by 1/10-inch thick stips of aluminum oxide fiber reinforced aluminum (known as FP/Al) were available as residual samples from another project. Ultrasonic and tensile test modulus determinations were conducted on a one-to-one basis and the data are given in Table 2. R was calculated from Equation (A-8). For these samples $L/h = 6.7$.

Several unidirectional fiber panels of Gr/Al, graphite fiber reinforced magnesium (Gr/Mg), graphite fiber reinforced copper (Gr/Cu), boron filament reinforced aluminum (B/Al), and silicon carbide reinforced aliminum (SCS/Al) were also evaluated. The panels were dedicated to other experiments as well as the present one and therefore could not be consumed entirely in this work. Ultrasonic wave speeds were determined in a manner thought to provide a representative value for a given panel. Subsequently, tensile tests were conducted on strips cut from the same panel. Panel descriptions and test results are summarized in Table 3. Each tensile test value listed is the average of at least two tests. The panel thicknesses ranged from 25 mil to approximately 100 mil. The value of R in Table 3 was calculated from Equation (A-5).

The ultrasonic approach to modulus determination was also evaluated for three types of simple structural elements (strut-type members) made of unidirection Gr/Al.

TABLE 1. ION-PLATED GR/AL TEST RESULTS

SPECIMEN NUMBER	DIMENSIONS AT TEST		DENSITY* GM /CC	V (AX) (mm/μsec)	E_{11} (MSI)	
	WIDTH* (INCH)	THICKNESS* (INCH)			PLATE WAVE VALUE	TENSILE TEST*
1	0.508	0.042	1.996	7.172	14.48	16.39
2	0.442	0.031	2.366	7.154	17.00	14.42
3	0.517	0.037	2.046	7.111	14.56	15.45
4	0.561	0.041	1.872	7.255	13.86	12.85
5	0.554	0.036	2.042	7.240	15.09	15.36
6	0.563	0.036	2.100	7.222	15.40	15.46
7	0.558	0.035	2.053	7.181	14.87	17.55
8	0.578	0.040	2.127	7.254	15.73	16.09
9	0.580	0.033	2.180	7.214	15.91	15.26
10	0.617	0.032	2.161	7.198	15.71	16.57
11	0.612	0.032	2.208	7.260	16.37	18.24
12	0.625	0.030	2.335	7.194	16.87	15.99
13	0.590	0.033	2.127	7.187	15.41	14.76
14	0.560	0.037	2.075	7.242	15.22	15.59
15	0.589	0.042	2.128	7.189	15.76	17.61
AVERAGE					15.48	15.84

* DATA FROM REF (3)

TABLE 2. FP/AL TEST RESULTS

SPECIMEN NUMBER	V_F (AX) (mm/μsec)	V_F (TR) (mm/μsec)	R	E_{11} (MSI)	
				PLATE WAVE VALUE	TENSILE TEST VALUE
7795-104-69	8.65	6.38	0.95	33.4	32.4
7795-104-70	8.55	6.48	0.95	32.6	31.2
7795-104-76	8.55	6.69	0.94	32.3	31.6
AVERAGE				32.8	31.7

COMPOSITE VENDOR: DUPONT
FAB. PROCESS: VACUUM METAL INFILTRATION
FIBER TYPE: Al_2O_3
MATRIX ALLOY: Al -2LI
DENSITY: 3.24 Gm/cm^3

TABLE 3. DESCRIPTION OF UNIDIRECTIONAL MMC PANELS AND TEST RESULTS

MMC VENDOR	PANEL IDEN. NO.	TYPE MMC	FAB. PROCESS	FIBER TYPE	MATRIX ALLOY	DENSITY (gm/cm^3)	THICKNESS (mm)	VF (AXIAL) (mm/μsec)	VF (TR) (mm/μsec)	R	E (MSI)	
											PLATE WAVE VALUE	TENSILE TEST VALUE
DWA	G5198	GR/AL	A	P55	6061	2.39	2.18	8.78	3.58	0.98	26.1	27.5
DWA	G4509	GR/AL	A	P55	A201	2.49	1.22	8.07	3.76	0.98	23.0	25.4
DWA	G4584	GR/AL	A	P100	6061	2.41	1.07	11.3	3.06	0.99	43.9	41.8
MCI	PBR10	GR/MG	B	P55	AZ91C	1.87 (b)	1.19	8.01	3.68	0.98	17.1	17.1
DWA	G5313	GR/MG	A	P100	AZ91C	1.88 (a)	0.61	12.2	3.59	0.99	40.2	41.5
AVCO	81-257A	B/AL	C	5.6 mil B/W	6061	2.54	0.76	9.71	7.50	0.95	33.0	31.7
AVCO	81-457	SIC/AL	D	SCS-2	6061	2.82	0.81	8.84	6.80	0.95	30.3	29.2
DWA	G5100	GR/AL	A	GY70	A201	2.52	0.66	8.84	3.88	0.98	28.0	28.0
DWA	G5232	GR/CU	A	P55	113	4.95 (b)	1.45	6.26	2.38	0.99	27.8	25.2

A. LIQUID METAL INFILTRATION + DIFFUSION BONDING
B. LIQUID METAL INFILTRATION + HOT ROLLING
C. DIFFUSION BONDING
D. PLASMA SPRAYED + CONSOLIDATED

(a) ESTIMATED VALUE
(b) DIMENSIONAL + WEIGHT VALUE

The fiber reinforcement is a pitch-based type known as P55 with a nominal diameter of 10 micron and nominal modulus of 55 MSI. Hardware fabrication was performed by Fiber Materials, Inc. (formerly Material Concepts, Inc.), of Columbus, Ohio, using a pultrusion process. Cross-sectional views of the three shapes are shown in Figure 1. Wave speeds in the fiber direction were determined over the full specimen length. The value R = 0.98 was used. The struts were subsequently tested to failure in axial compression with the ends fully restrained against rotation. Testing was performed by Measurements Technology, Inc., Roswell, Georgia. Eighteen specimens were tested overall. From the slenderness ratio (length/radius of gyration) all struts were classified as short columns, thus indicating that plastic failure would precede stability failure. Tables 4, 5, and 6 give the density and test results for the structural members.

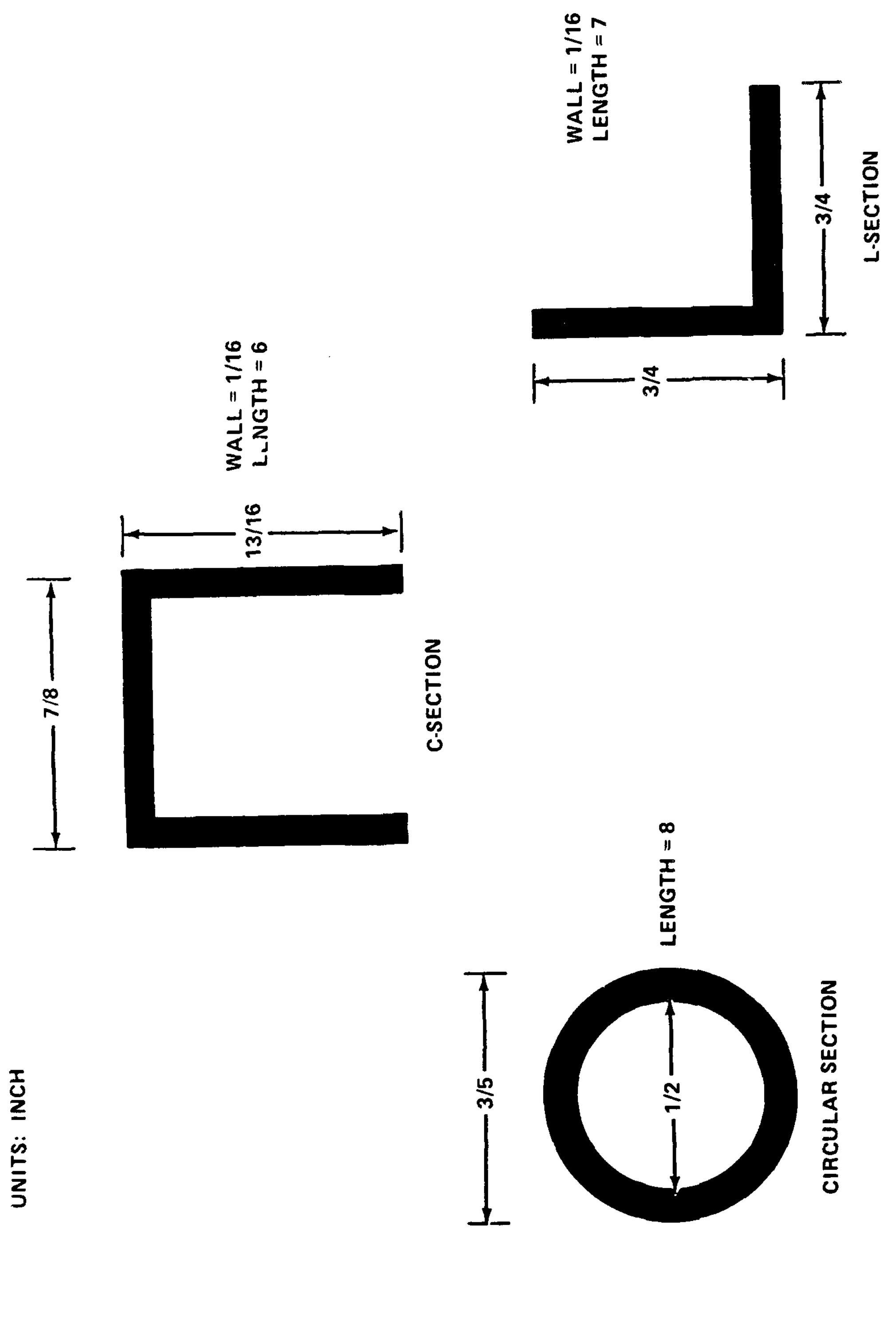

FIGURE 1. NOMINAL GEOMETRY PARAMETERS FOR P55/6061 STRUCTURAL ELEMENTS

TABLE 4. GR/AL CIRCULAR SECTION TEST RESULTS
$p = 2.40\ gm/cm^3$

SPECIMEN NUMBER	V_F (AX) (mm/μsec)	E_{11} (MSI)	
		PLATE WAVE	COMPRESSION TEST
336-8A	8.70	25.8	23.1
336-15	8.56	25.0	25.5
336-9	8.62	25.3	23.5
100-43	8.66	25.6	24.9
336-8B	8.85	26.7	23.6
AVERAGE		25.7	24.1

TABLE 5. GR/AL C-SECTION TEST RESULTS
$p = 2.41\ gm/cm^3$

SPECIMEN NUMBER	V_F (AX) (mm/μsec)	E_{11} (MSI)	
		PLATE WAVE	COMPRESSION TEST
593B	8.64	25.6	24.8
592A	8.54	25.0	22.6
590	8.68	25.8	23.9
588	8.71	26.0	23.6
591	8.80	26.5	24.3
592	–	–	29.7
AVERAGE		25.6	24.8

TABLE 6. GR/AL L-SECTION TEST RESULTS
p = 2.41 gm/cm^3

SPECIMEN NUMBER	V_F (AX) (mm/µsec)	E_{11} (MSI)	
		PLATE WAVE	COMPRESSION TEST
584-6	8.61	25.4	26.8
584-5	8.60	25.0	25.1
583-7	8.55	25.0	32.2
584-4	8.55	25.3	24.8
585-1	8.66	25.7	23.4
585-5	8.68	25.8	22.7
AVERAGE		25.4	25.8

ANALYSIS

In Figure 2 the ultrasonic values for Young's modulus are plotted against the mechanical test values for all experiments conducted. The points shown are the average moduli of Tables 1, 2, 4, 5, and 6 and all the moduli of Table 3. Perfect agreement would be exhibited by the points lying on a straight line through the origin inclined at 45° to the axes. A straight line

$$E_{11U} = A + B E_{11M} \tag{3}$$

where E_{11U} is the ultrasonic test modulus and E_{11M} the mechanical test modulus, was fit to this data by the method of least-square-errors as applied to a Gaussian distribution. All statistical methods used in this report are described by Bevington.[4] A and B are constants to be determined from the curve fitting procedure. For perfect agreement between the test results:

$$A = 0 \text{ MSI}, B = 1 \text{ MSI}^{-1}.$$

The analysis yields:

$$A = (-0.4 \pm 1.6) \text{ MSI},$$

$$B = (1.03 \pm 0.06) \text{ MSI}^{-1}$$

(the uncertainty is one standard deviation). The agreement is within the uncertainty of the experiments.

The linear-correlation coefficient, r, was used to further investigate this agreement. This coefficient is a statistical parameter which provides a measure of the degree of linear correspondence that exists between two observed quantities. The absolute value of r ranges from 0, when there is no correlation, to 1, when there is one hundred percent correlation. The r for the data set of Figure 2 was calculated as $r = 0.98$, indicating that a high correlation between the two test methods exists.

The probable error, P.E., is a quantity calculated from a data set which gives an estimate of the uncertainty in the dependent variable over the data set as a whole. For the data set of Figure 2, the P.E. = 0.98 MSI. That is, an ultrasonic determination of Young's modulus should lie within approximately one MSI of the mechanical test value for any material tested.

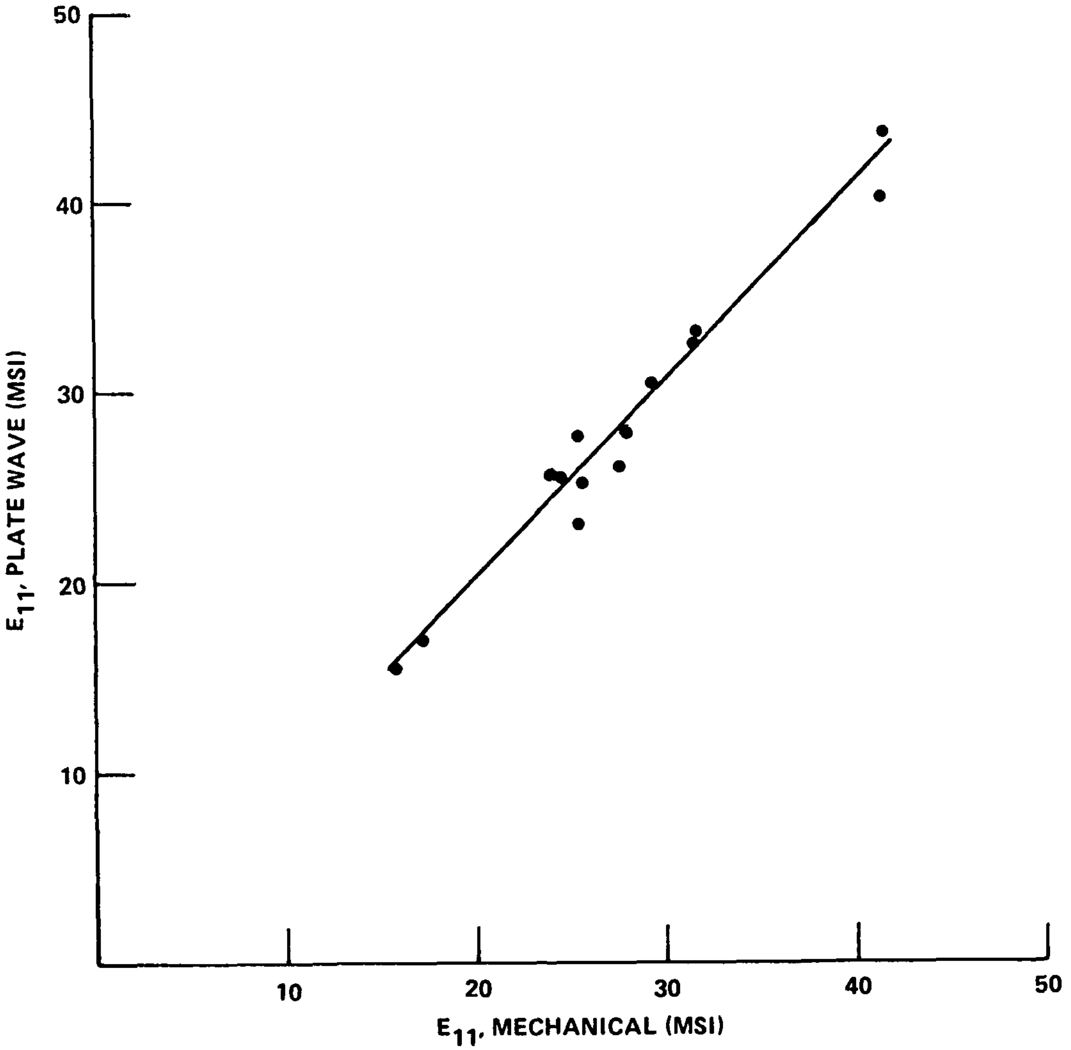

FIGURE 2. PLATE WAVE AND MECHANICAL TEST VALUES OF YOUNG'S MODULUS FOR UNIDIRECTIONAL MMCS

CONCLUSIONS

The ultrasonic values of Young's moduli correlated well with the mechanical test results for a variety of unidirectional MMCs. The discrepancy between the moduli determined by the two methods is approximately one MSI. Therefore, the ultrasonic method is deemed reliable for determining Young's moduli in these unidirectionally reinforced MMCs.

REFERENCES

1. Foltz, J.V., Bertram, A.L., and Anderson,, C.W., *A Method to Determine Dynamic Elastic Constants of Thin Shell Composites by Guided Ultrasonic Waves*. NSWC TR 85-186.

2. Kolsky, H., *Stress Waves in Solids*, New York, Dover, 1963, p. 83.

3. Karmarkar, S.D. and Divecha, A.P., *Characterization of Ion-Plated Graphite Aluminum Composites*, NSWC TR 82-220.

4. Bevington, Philip R., *Data Reduction and Error Analysis for the Physical Sciences*, McGraw-Hill, 1969.

APPENDIX

The parameter R is given by the expression [A 1]

$$R = 1 - v_{12} v_{21} \tag{A-1}$$

where the v_{12} and v_{21} are the major and minor Poisson ratios of the unidirectional lamina.[A 1]

$$v_{21} = v_{12} E_{22}/E_{11} \tag{A-2}$$

E_{11} and E_{22} are the lamina moduli in the fiber and transverse directions, respectively. The ratio of moduli may be determined if the ultrasonic wave speeds are known in both the fiber and transverse directions,[A 2]

$$E_{22}/E_{11} = (V_{22}/V_{11})^2 \tag{A-3}$$

Then Equation (A-1) becomes

$$R = 1 - (v_{12} V_{22}/V_{11})^2 \tag{A-4}$$

The second term on the right-hand side of Equation (A-4) is much smaller than the first. A reasonable estimate of v_{12} for the present MMCs is 0.3. Then

$$R = 1 - (0.09)(V_{22}/V_{11})^2 \tag{A-5}$$

REFERENCES

A-1. Ashton, J. E., Halpin, J. C. and Petit, P. H., *Primer on Composite Materials: Analysis*, Published by Technomic, 1969, Chapter 2.

A-2. Foltz, J. V., Bertram, A. L. and Anderson, C. W., *A Method to Determine Dynamic Elastic Constants of Thin Shell Composites by Guided Ultrastonic Waves*, NSWC TR 85-186.

DISTRIBUTION

	Copies
Office of Director of Defense Research and Engineering Attn: J. Persh Staff Specialist for Materials and Structures Room 3D1089, The Pentagon Washington, DC 20301	 1
Office of Chief of Naval Research Attn: W. Messick, ONT Code 225 800 N. Quincy Street Arlington, VA 22217-5000	 1
Advanced Submarine Technology Office Attn: J. Kelly 1515 Wilson Blvd. Arlington, VA 22209	 1
Department of the Navy Strategic Systems Project Office Attn: B. W. Hannah, SP272 Crystal Mall No. 3 Washington, DC 20362	 1
Office of Chief of Naval Research Attn: R. Pohanka, OCNR Code 1131 Y. Rajapakse, OCNR Code 1132SM 800 N. Quincy Street Arlington, VA 22217-5000	 1 1
Commander David Taylor Research Center Attn: J. Gudas, Code 2814 A. G. S. Morton, Code 2813 Annapolis, MD 21402	 1 1
Commander Naval Ocean Systems Center Attn: P. D. Burke, Code 9322 San Diego, CA 91252-5000	 1
Commander Naval Air Development Center Attn: T. E. Hess, Code 6043 G. London, Code 606D I. Shaffer, Code 60C Warminister, PA 18974	 1 1 1
Naval Research Laboratory Attn: S. C. Sanday, Code 6370 I. Wolock, Code 6383 H. Chaskelis, Code 5834 4555 Overlook Avenue Washington, DC 20375	 1 1 1
Commanding Officer Naval Underwater Systems Center Attn: B. Sandman, Code 3636 Newport, RI 02840	 1
Naval Intelligence Support Center Attn: M. E. Andrasco 4301 Suitland Road Washington, DC 20390	 1
NAVPRO, Sunnyvale Attn: B. Galligan, SPL 312 Lockhed Bldg. 181 Sunnyvale, CA 94086	 1
Metal Matrix Composites Information Analysis Center Kaman Tempo Attn: W. McNamara 816 State Street P.O. Drawer QQ Santa Barbara, CA 93102-1479	 2

DISTRIBUTION (Cont.)

	Copies
Defense Technical Information Center Cameron Station Alexandria, VA 22314	2
Strategic Defense Initiative Organization Attn: M. Obal SDIO/T/KT Washington, DC 20301-7100	1
Defense Advanced Research Projects Agency Attn: B. Wilcox Materials Sciences Division 1400 Wilson Blvd. Arlington, VA 22209	1
Wright Research and Development Center Attn: J. Gunderson, WRDC/MLLN	1
J. R. Williamson, WRDC/MLB	1
S. Schwenker, WRDC/MLLS	1
D. E. Beeler, WRDC/MLTN	1
V. Johnson, WRDC/FIBAA	1
L. Kelly, WRDC/FIBAA	1
D. Roselius Wright-Patterson AFB, OH 45433-6523	1
Air Force Systems Command Attn: F. D. Boensch, AFSC/NAC	1
T. M. F. Ronald, AFSC/NAT Wright-Patterson AFB, OH 45433-6503	1
Department of the Army U.S. Army Materials Technology Laboratory Attn: A. Levitt, SLCMT-MCD-E	1
P. Smoot, SLKCMT-MCD-E Watertown, MA 02172-0001	1
U.S. Army Mobility Equipment Research and Development Command Attn: G. D. Farmer, Jr., DRDME-VM Fort Belvoir, VA 22060	1

	Copies
Ballistic Missile Defense Materials Program Office U.S. Army Materials Technology Laboratory Attn: J. Dignam Watertown, MA 02172-0001	1
Ballistic Missile Defense Office BMD-ATC Attn: M. L. Whitfield P.O. Box 1500 Huntsville, AL 35807	1
Army Foreign Science and Technology Center Attn: J. F. Crider, FSTC/DRXST-MTI 220 7th Street Charlottesville, VA 22901	1
NASA Headquarters/RTM Attn: S. Venneri 600 Independence Avenue, SW Washington, DC 20546	1
NASA/Langley Research Center Attn: D. Tenney, Code MS188M	1
S. Tompkins, Code 191 Hampton, VA 23665-5225	1
NASA/Lewis Research Center Attn: D. L. McDanels 21000 Brookpark Road Cleveland, OH 44135	1
NASA/Johnson Space Center Attn: L. Leger, Code ES 53 Houston, TXC 77058	1
Marshall Space Flight Center Attn: E. Engler, Mail Stop EP13 Huntsville, AL 35812	1

DISTRIBUTION (Cont.)

	Copies
The Aerospace Corporation	
Attn: G. Steckel, MS M2/321	1
H. Katzman, MS M2/242	1
G. Hawkins, MS M2/250	1
W. Kao, MS M2/242	1
L. Rubin, MS M2/250	1
M. Aswani, MS M4/920	1
P.O. Box 92957	
Los Angeles, CA 90009-2957	
Johns Hopkins University	
Applied Physics Laboratory	
Johns Hopkins Road	
Laurel, MD	1
Jet Propulsion Laboratory	
Attn: R. H. Smoak,	
Mail Stop 67-201	1
4800 Oak Grove Drive	
Pasadena, CA 91103	
Sandia National Laboratories	
Attn: B. C. Odegard,	
Division 8316	1
Livermore, CA 94550	
Amercom, Inc.	
Attn: J. M. Shoemaker	1
8928 Fullbright Aenue	
Chatsworth, CA 91311	
DWA Composite Specialities, Inc.	
Attn: J. Dolowy	1
21119 Superior Street	
Chatsworth, CA 91311-4393	
Advanced Composite Materials Corporation	
Attn: P. E. Hood	1
1525 S. Buncombe Road	
Greer, SC 29651-9208	
Fiber Materials, Inc.	
Attn: J. Jacox	1
666 North Hague Avenue	
Columbus, OH 43204	

	Copies
American Cyanamid Company	
Attn: D. A. Foster	1
1937 West Main Street	
P.O. Box 60	
Stamford, CT 06904-0060	
Research Opportunities, Inc.	
Attn: W. C. Riley	1
2200 Amapola Court	
Torrance, CA 90501	
Materials Sciences Corporation	
Attn: B. W. Rosen	1
Gwynedd Plaza II, Bethlehem Pike	
P.O. Box 206	
Spring House, PA 19477	
The Charles Stark Draper Laboratory	
Attn: J. Gubbay, MS37	1
555 Technology Sqauare	
Cambridge, MA 02139	
Atlantic Research Corporation	
Attn: J. Baetz	1
5390 Cherokee Avenue	
Alexandria, VA 22314	
Fiber Materials, Inc.	
Attn: R. I. Pepper, Director	
Research & Development	1
Biddeford Industrial Park	
Biddeford, ME 04005	
United Technologies Research Center	
Attn: K. M. Prewo	1
R. W. Reed, MS86	1
East Hartford, CT 06108	
Pratt & Whitney	
Attn: A. Adair	1
P.O. Box 109600	
West Palm Beach, FL 33410-9600	

DISTRIBUTION (Cont.)

	Copies
Lockheed Missiles & Space Company, Inc	
Attn: A. A. Woods, D50-43/B590	1
W. W. Sable, D62-17/B104	1
R. Dotson, D62-18/B104	1
J. H. Fyten, D62-92/B564	1
J. T. McGrath, D81-32/B157	1
K. Benner, D59-60/B556	1
B. K. Min, D59-60/B556	1
R. D. Torczyner, D59-60/B556	1
P.O. Box 3504	
Sunnyvale, CA 94088-3504	
Lockheed R&D Palo Alto Research Laboratory	
Attn: F. W. Crossman D93-10/B204	1
3251 Hanover Street	
Palo Alto, CA 94304	
Lockheed California Company	
Attn: D. Chellman, D76-31/B63	1
M. A. Steinberg, D03-10/B61	1
P.O. Box 551	
Burbank, CA 91520	
TRW Electronics and Defense	
Attn: R. Claridge, 01/2220	1
J. Bohn, 01/2210	1
One Space Park	
Redondo Beach, CA 90278	
Westinghouse Defense and Electronics Center Development & Operations Division	
Attn: J. D. Gardner	1
P.O. Box 746-MS 369	
Baltimore, MD 21203	
LTV Aerospace and Defense Company Vought Missiles and Advanced Programs Division	
Attn: C. M Standard, M/S TH83	1
P.O. Box 225907	
Dallas, TX 75265	

	Copies
Vought Corporation Advanced Technology Center	
Attn: R. C. Van Sielen	1
P.O. Box 225907	
Dallas, TX 75265	
Hughes Aircraft Company	
Attn. R. W. Seibold	1
Bldg. E-1, Mail Station F150	
P.O. Box 902	
El Segundo, CA 90245-0902	
Boeing Aerospace	
Attn: T. S. Luhman, MS 73-09	1
P. Rimbos, MS 82-97	1
P.O. Box 3999	
Seattle, WA 98124-2499	
Boeing Vertol Company	
Attn: R. L. Pinckney, Mail Stop P32-12	1
G. B. Wadsworth, Mail Stop P38-21	1
P.O. Box 16858	
Philadephia, PA 19142	
GE Astro Space Division	
Attn: C. Zweben	1
Bldg. 100, Rm M4018	
P.O. Box 8555	
Philadephia, PA 19101	
McDonnell Douglas Corporation	
Attn: B. Leonard	1
L. Cohen	1
5301 Bolsa Avenue	
Huntington Beach, CA 92647	
Hughes Aircraft Company Space and Communications	
Attn: D. E. Nelson, S33/C339	1
Los Angeles, CA 90009	

DISTRIBUTION (Cont.)

	Copies
General Dynamics Fort Worth Division Attn: A. Chaput, MZ5969 P.O. Box 748 Fort Worth, TX 76101	1
McDonnell Douglas Corporation Attn: B. A. Cramer, Bldg. 106/L2/MS22	1
D. Chong, Bldg. 467/HQ/MS329	1
N. Newman P.O. Box 516 St. Louis, MO 63166	1
Martin Marietta Orlando Aerospace Attn: W. Meyerer, MP 150 P.O. Box 5837 Orlando, FL 32855	1
Rockwell International Corporation North American Aircraft Operaions Attn: B. A. Burroughs 201 North Douglas Street El Segundo, CA 90245	1
Rockwell International Corporation North American Aircraft Operations Attn: A. Bakalyar 2770 East Carson Street Lakewood, CA 90712	1
Rockwell International Corporation Rocketdyne Division Attn: N. Payton 6633 Canaoga Avenue Canoga Park, CA 91304	1
Ball Aerospace Systems Division Attn: D. Lemon	1
H. W. Davis P.O. Box 1062 Boulder, CO 80306	1

	Copies
Aluminum Company of America Alcoa Laboratories Alcoa Technical Center Attn: T. B. Gurganus Alcoa Center, PA 15069	1
Amoco Performance Products, Inc. Attn: L. Matthews 38C Grove Street Ridgefield, CT 06877	1
E. I. DuPont Denemours & Company Central Research and Development Department Attn: A. K. Dhingra Room D-6005 Wilmington, DE 19898	1
Ketema Attn: W. E. Davis 3611 South Harbor Blvd. Suite 225 Santa Ana, CA 92704	1
Gould, Inc. Attn: E. Thellman Ocean Systems Division 18901 Euclid Avenue Cleveland, OH 44117	1
Textron Specialty Materials Attn: P. R. Hoffman Two Industrial Avenue Lowell, MA 01851	1
ARTECH Corporation Attn: H. Hahn 2901 Telstar Court Falls Church, VA 22042	1
The Marquardt Company Attn: M. Katcher P. O. Box 201 Van Nuys, CA 91409	1

DISTRIBUTION (Cont.)

	Copies
General Motors Corporation Detroit Diesel-Allison Attn: P. S. O'Connell P.O. Box 420 Indianapolis, IN 46206-0420 Speed Code T9	1
Sparta, Inc. Attn: H. Rediess 23041 de la Carlota, Suite 210 Laguna Hills, CA 92653-1507	1
Sparta, Inc. Attn: J. Glatz 4520 Executive Dr., Suite 210 San Diego, CA 92121	1
Southern Research Institute Attn: H. S. Starrett P.O. Box 55303 Birmingham, AL 35255	1
Center for Naval Analyses 4402 Fort Avenue P.O. Box 16268 Alexandria, VA 22303-0268	1
Advanced Materials Laboratory 110 Hillcrest Road Concord, MA 01742	1
Nevada Engineering & Tech. Corporation Attn: R. G. Sherman 592 Dryad Road Santa Monica, CA 90402	1

Internal Distribution	Copies
E231	2
E232	3
R30 (C. Mueller	1
R32 (P. Hesse)	1
R32 (J. Foltz)	5
R32 (A. Bertram)	5
R32 (J. Tydings)	1
R32 (R. Garrett)	1
R32 (J. Clark)	1
R34 (C. Anderson)	1
R34 (J. Liu)	1
R34 (R. Lee)	1
R35 (C. Blackmon)	1
R35 (R. Lowry)	1
K205 (W. Messick)	1
K22 (E. Becker)	1
C72W (R. Johnson)	1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
5 August 1991

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
A Comparison of Ultrasonic and Mechanical Values of the Principal Young's Modulus of Unidirectional Metal Matrix Composites

5. FUNDING NUMBERS

6. AUTHOR(S)
John V. Foltz and Albert L. Bertram

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center
10901 New Hampshire Avenue
Silver Spring, MD 20903-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NAVSWC TR 91-446

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

A method of determining the fiber direction elastic modulus of a thin-ply unidirectional fiber reinforced metal matrix composite using ultrasonic plate waves is described. The results obtained by the ultrasonic technique are compared to values of Young's modulus from mechanical tests on the same materials. The agreement shows that the ultrasonic method is a reliable and essentially nondestructive way of determining Young's moduli in thin unidirectionally reinforced metal matrix composites.

14. SUBJECT TERMS
ultrasonic characterization, graphite/aluminum, graphite/magnesium, graphite/copper, boron aluminum, metal matrix composites, nondestructive evaluation

15. NUMBER OF PAGES
31

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and its title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	**PR**	- Project
G	- Grant	**TA**	- Task
PE	- Program Element	**WU**	- Work Unit Accession No.

BLOCK 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If Known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD	- See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE	- See authorities.
NASA	- See Handbook NHB 2200.2
NTIS	- Leave blank.

Block 12b. Distribution Code.

DOD	- Leave blank.
DOE	- Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA	- Leave blank.
NTIS	- Leave blank.

Block 13. Abstract. Include a brief ***(Maximum 200 words)*** factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code ***(NTIS only)***.

Blocks 17.-19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.